Array Antenna for Synthetic Aperture Radar Operating in X and Ku-Bands: A Study to Enhance Isolation Between Radiation Elements

Mohammad Alibakhshikenari[1], Bal S. Virdee[2], Chan H. See[3], Raed Abd-Alhameed[4], Francisco Falcone[5], and Ernesto Limiti[1]

[1]Electronics Engineering Department, University of Rome “Tor Vergata”, Via del politecnico 00133, Rome, ITALY

[2]London Metropolitan University, Center for Communications Technology & Mathematics, School of Computing & Digital Media, London N7 8DB, UK

[3] School of Engineering Department, University of Bolton, Deane Road, Bolton, BL3 5AB, UK

[4]School of Electrical Engineering & Computer Science, University of Bradford, UK

[5]Electric and Electronic Engineering Department of the Universidad Pública de Navarra, SPAIN

alibakhshikenari@ing.uniroma2.it

***Abstract-* Modern synthetic aperture radars (SAR) require a system bandwidth of greater than 1 GHz. Waveguide slot antennas are popular for use in SAR applications because of their inherent advantages, namely high efficiency and power handling capability, but such antennas have a limited bandwidth. Although the bandwidth of slot antennas can be broadened by using ridge waveguides however this approach introduces manufacturing complexity and is costly. A novel solution is presented in this paper to realise a large bandwidth by using 2×3 array antenna where the mutual coupling between the radiating elements is suppressed by inserting an isolation wall between the radiating elements. The isolation wall comprises three intercoupled U-shaped microstrip transmission-lines. With this technique the antenna's bandwidth for VSWR<1.5 is greater than 2 GHz inside the X- and Ku-bands.**

***Keywords-* Synthetic aperture radar (SAR), decoupling, meander lines, array antennas.**

I. INTRODUCTION

Synthetic aperture radars are extensively used for high-resolution spaceborne and airborne applications for monitoring the weather, climate change, earth resource mapping, and military systems. SAR systems take advantage of the long-range propagation characteristics of radar signals and the complex information processing to provide high resolution imagery. Slant-range spatial resolution (ρ_r) of SAR systems is a function of the system bandwidth, given by [1][2]:

$$\rho_r = {}^{c}/_{2B} \qquad (1)$$

where c is speed of the light, and B is the system bandwidth. It is evident from this equation that when the slant-range spatial resolution is required to be better than 0.2m, the system bandwidth needs to be greater than 1 GHz.

Numerous SAR satellite programs including RadarSAT-1, X-SAR, and ERS-1/2 have adopted waveguide slot array antennas because of their inherent advantages of high efficiency, mechanical strength, high power handling capability, and ease of fabrication. Conventional waveguide slot array antennas unfortunately have a limited bandwidth. To overcome this deficiency several approaches have been investigated in the past to enhance the bandwidth of such antennas. In one method the array is divides into sub-arrays that are fed through power dividers, but the associated loss is considerably high. Although the bandwidth using ridged waveguide can be improved it is considerably difficult to manufacture the ridges, which exacerbates the antennas cost [3]-[5].

Other than bandwidth requirements mutual coupling between the antenna needs to be minimal, which could significantly degrade the antenna's radiation pattern and gain performance, as well as contribute to crosstalks between neighboring antenna elements. Mutual coupling is higher for antenna elements which are spaced less than half-wavelength. Ideally, antenna elements should be highly isolated from each other to achieve desired performance from array antennas. Various techniques have previously been proposed to minimize the mutual interference between the antenna elements and to improve the isolation between the elements [6]-[11]. The basic principle is to involves embedding between the array antenna elements various structures, namely: (i) defected ground; (ii) electromagnetic bandgap; (iii) parasitic element; (iv) neutralization line; (v) metamaterial, etc. The structures reported to-date can suffer from fabrication complexity, having a large resonant frequency mismatch between S_{11} and S_{22}, degraded antenna radiation patterns and efficiency, not having acceptable isolation over the whole system bandwidth, or narrow frequency bandwidth.

In this paper, a 2×3 array antenna is presented that has a wide bandwidth for high-resolution synthetic aperture radar applications. The proposed array antenna is a symmetrical configuration with six radiation elements separated edge-to-edge by only $0.37\lambda_0$ (10 mm) whose bandwidth is within X- and Ku-bands, i.e. 11.2 to 13.5 GHz, corresponding to 18.62% fractional bandwidth. Isolation between the adjacent antenna elements is improved by inserting an isolation wall between the radiating elements. The isolation wall is implemented with three intercoupled U-shaped transmission-lines. Parametric study on the effects of the isolation wall was conducted to optimise the antenna's performance. The results show by applying this simple isolation technique the level of decoupling between all array elements have dramatically improved.

II. Proposed Mutual Coupling Based on Transmission Line Isolation Wall

Fig.1 shows 2×3 array antenna which is implemented with six standard patch antennas. Mutual coupling between the patches is reduced by inserting an isolation wall between the patch antennas. The isolation wall is three intercoupled U-shaped microstrip transmission-lines that behaves essentially as an electrical resonator resulting from oscillation of currents induced within the structure. In fact, the isolation wall increases the slow wave factor to thereby perturb the current that flows through the microstrip structure. This creates a bandgap that blocks the surface currents at its resonant frequency. This structure when employed as a decoupling unit acts like a band reject filter whose fundamental resonant frequency is controlled by the length of the three U-shaped microstrip transmission-lines. The array antenna and isolation wall were constructed on FR-4 substrate material with height of 1.6 mm, dielectric constant of 4.3, and loss tangent of 0.025. The antenna's performance with and without the isolation wall was analysed using CST Microwave Studio (Version 2016). The array antenna was excited simultaneously through the six designated waveguide ports in the *yz*-plane, shown in Fig.1. The reflection and transmission characteristics of the simulation analysis are as shown in Fig.2, where the bandwidth is defined for S_{11}<-10dB. The proposed mutual coupling isolation wall exhibits a sharp rejection at a frequency of 12.7 GHz when the width of the U-shaped transmission-lines is 0.5mm and the gap between the lines is 1mm. These dimensions result in band reject function between 11.2 and 13.5 GHz for isolation greater than -15dB between the ports.

With no wall the maximum isolation between elements #1 and #2; #1 and #3; #1 and #4; #1 and #5; #1 and #6; #2 and #3; #2 and #5; #3 and #4; #3 and #5; #4 and #5; #4 and #6; #5 and #6 is -26, -17, -36, -17, -36, -36, -36, -31, -33, -34.5, -31, and -30.3, respectively. After applying the isolation wall the maximum isolation between corresponding elements as above significantly improve to: -33, -33, -55, -33, -55, -58, -66.5, -71, -60, -56.3, -66, and -70.3, respectively. It is noted in each case the isolation has improved by a factor of at least two. In other words, the isolation improvements between aforementioned elements is: -7dB, -16dB, -19dB, -16dB, -19dB, -22dB, -30.5dB, -40dB, -27dB, -22dB, -35dB, and -40dB, respectively.

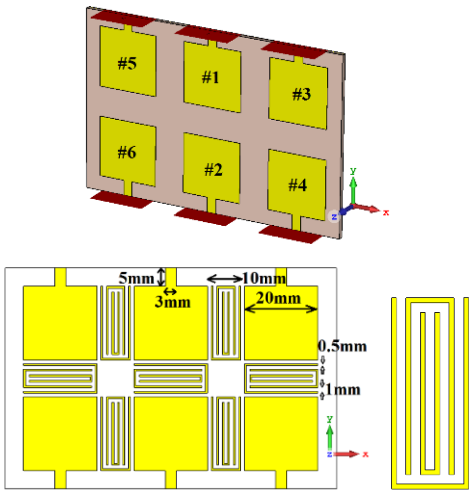
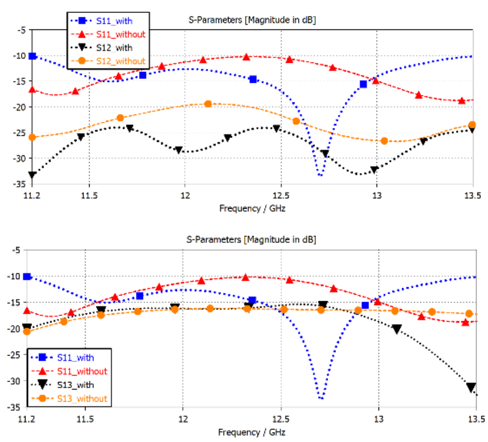
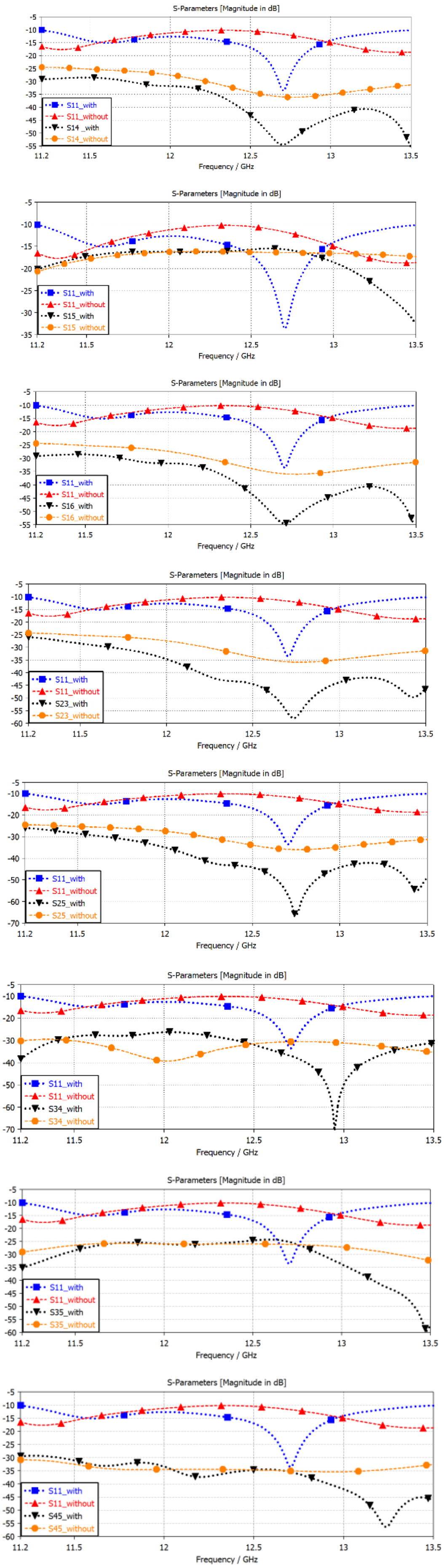


Fig.1. Proposed array antenna without and with isolation wall.





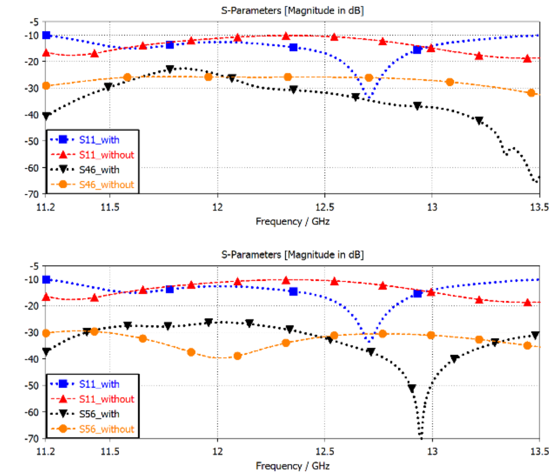
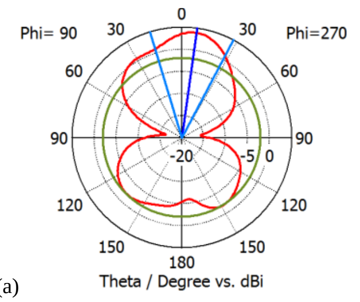


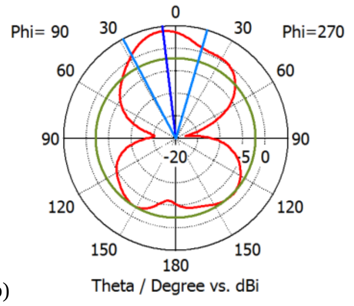
Fig.2. Reflection and transmission response where the bandwidth is defined for S_{11}<-10dB. Other corresponding S-parameters are identical due to the symmetrical configuration of the array antenna.

The array antenna's radiation patterns for both cases with and without the isolation wall at the antenna's resonance frequency of 12.7 GHz are plotted in Fig.3. These results show no obvious degradation in the radiation characteristics of the array radiation without and with the isolation wall. In fact, this implies the isolation wall could be inserted retrospectively to reduce mutual coupling in planar antennas.

The array antenna's radiation gain without and with the isolation wall varies from 3.91dBi to 6.80dBi, and from 4.45dBi to 8.5dBi, respectively.



(a)



(b)

Fig.3. Radiation patterns at the resonance frequency of 12.7 GHz, (a) without isolation wall, and (b) with isolation wall.

The array antenna's performance is compared and validated with other recent mutual coupling reduction techniques in Table I. The results, shows that the proposed array antenna has a wide bandwidth of more than 2 GHz from 11.2 – 13.5 GHz (18.62% fractional bandwidth) to support part of X- and Ku- bands. The other antennas in Table I apply mutual coupling reduction to just 1×1 array antenna, whereas here we have applied the proposed isolation wall to 2×3 array antenna configuration. The results show with the proposed isolation wall a higher isolation between antennas is achieved, and the radiation pattern remains essentially intact. The proposed isolation wall is of a simple construction, which can be applied retrospectively to existing planar array antennas. In addition, unlike other techniques the proposed technique does not require any via holes and/or defected ground plane.

TABLE I. Proposed Array Antenna Characteristics Compared with Recent Works

Ref.	Method	Max. isolation improvement	BW	Rad. pattern deterioration	No. of elements
[12]	EBG	4 dB	Narrow	Yes	2
[13]	UC-EBG	10 dB	Narrow	Yes	2
[14]	Compact EBG	17 dB	Narrow	Yes	2
[15]	DGS	17.43 dB	Narrow	Yes	2
[16]	U-Shaped Resonator	10 dB	Narrow	Yes	2
[17]	Slotted Meander Line Resonator	16 dB	Narrow	Yes	2
[18]	I-Shaped Resonator	30 dB	Narrow	Yes	2
[19]	Slot in Ground plane	40 dB	Narrow	Yes	2
[20]	SCSRR	10 dB	Narrow	Yes	2
[21]	SCSSRR	14.6 dB	Narrow	Yes	2
[22]	W/g MTM	20 dB	Narrow	No	2
[23]	W/g MTM	18 dB	Narrow	No	2
[24]	Meander Line Resonator	10 dB	Narrow	No	2
[25]	Fractal load with DGS	16 dB	Narrow	No	2
This work	Triple U-Shaped Coupled Lines	S12: 7 dB S13: 16 dB S14: 19 dB S15: 16 dB S16: 19 dB S23: 22 dB S25: 31 dB S34: 40 dB S35: 27 dB S45: 22 dB S46: 35 dB S56: 40 dB	Wide	No	6

III. CONCLUSION

A novel technique is shown to significantly enhance isolation between radiating elements in a 2×3 array antenna. This is achieved by simply inserting an isolation wall comprising three intercoupled U-shaped microstrip transmission-lines. The proposed technique offers a wide bandwidth operation greater than 2 GHz inside the X- and Ku-bands, which is necessary for SAR systems, and has minimal affect on the antenna's radiation patterns. The isolation wall is simple to fabricate and does not require any via-holes or defected ground plane.

REFERENCES

[1] A. Currie, and M.A. Brown, "Wide-swath SAR", IEEE. Proceeding, vol.139, pp. 122-135, April 1992.
[2] J. Granholm, N. Skou, "Dual-polarization, wideband microstrip antenna array for airborne C-band SAR", IEEE International Conference on Phased Array Systems and Technology, pp. 243-326, 2000
[3] D.Y. Kim, and R.S. Elliot, "A design procedure for slot arrays fed by single-ridge waveguide", IEEE. Trans. Antennas. Propogat, vol. 11, pp.1531-1536,November 1988.
[4] J. Green, H. Shnitkin, and P.J. Bertalan, "Asymmetric ridged waveguide radiating element for a scanned planar array", IEEE. Trans. Antennas. Propogat, vol. 8, pp. 1161-1165, August 1990.
[5] W. Wang, S.S. Zhong, Y.M. Zhang, and X.L. Liang, "A broadband slotted ridged antenna array", IEEE. Trans. Antennas. Propogat, vol.54, pp. 2416- 2420, August 2006.
[6] H. -S. Lui, H. T. Hui, and M. S. Leong, "A note on the mutual-coupling problems in transmitting and receiving antenna arrays," *IEEE Antennas Propag. Mag.*, vol. 51, no. 5, pp. 171–176, Oct. 2009.
[7] H. -S. Lui and H. T. Hui, "Improved mutual coupling compensation in compact antenna arrays," *Microw., Antennas Propag.*, vol. 4, no. 10, pp. 1506–1516, 2010.
[8] A. H. Mohammadian, N. M. Martin, and D. W. Griffin, "A theoretical and experimental study of mutual coupling in microstrip antenna arrays," *IEEE Trans. Antennas Propag.*, vol. 37, no. 10, pp. 1217–1223, Oct. 1989.
[9] F. Yang and Y. Rahamat-samii, "Microstrip antennas integrated with electromagnetic band-gap (EBG) structures: A low mutual coupling design for array applications," *IEEE Trans. Antennas Propag.*, vol. 51, no. 10, pp. 2936–2946, Oct. 2003.
[10] M. M. Bait-Suwailam, O. F. Siddiqui, and O. M. Ramahi, "Mutual coupling reduction between microstrip patch antennas using slotted complementary split-ring resonators," *IEEE Antennas Wireless Propag. Lett.*, vol. 9, pp. 876–878, 2010.
[11] A. Habashi, J. Nourinia, and C. Ghobadi, "Mutual coupling reduction between very closely spaced patch antennas using low-profile folded splitring resonators (FSRRs)," *IEEE Antennas Wireless Propag. Lett.*, vol. 10, pp. 862–865, 2011.
[12] Yu, A. and X. Zhang, "A novel method to improve the performance of microstrip antenna arrays using a dumbbell EBG structure," *IEEE Antennas Wireless Propagation Letters*, Vol. 2, No. 1, 170-172, 2003.
[13] Farahani, H. S., M. Veysi, M. Kamyab, and A. Tadjalli, "Mutual coupling reduction in patch antenna arrays using a UC-EBG superstate," *IEEE Antennas Wireless Propagation Letters*, Vol. 9, 57-59, 2010.
[14] Islam, M. T. and M. S. Alam, "Compact EBG structure for alleviating mutual coupling between patch antenna array elements," *Progress In Electromagnetics Research*, Vol. 137, 425-438, 2013.
[15] Zhu, F. G., J. D. Xu, and Q. Xu, "Reduction of mutual coupling between closely packed antenna elements using defected ground structure," *Electronics Letters*, Vol. 45 , No. 12, 601-602, 2012.
[16] Farsi, S., D. Schreurs, and B. Nauwelaers, "Mutual coupling reduction of planar antenna by using a simple microstrip u-section," *IEEE Antennas and Wireless Propagation Letters*, Vol. 11, 1501 1503, 2012.
[17] Alsath, M. G., M. Kanagasabai, and B. Balasubramanian, "Implementation of slotted meander line resonators for isolation enhancement in microstrip patch antenna arrays," *IEEE Antennas and Wireless Propagation Letters*, Vol. 12, 15-18, 2013.
[18] Ghosh. C. K. and S. K. Parui, "Reduction of mutual coupling between E-shaped microstrip antennas by using a simple microstrip I-section," *Microwave and Optical Technology Letters*, Vol. 55, No. 11, 2544-2549, 2013.

[19] OuYang, J., F. Yang, and Z. M. Wang, "Reduction of mutual coupling of closely spaced microstrip MIMO antennas for WLAN application," *IEEE Antennas Wireless Propagation Letters*, Vol. 10, 310-312, 2011.
[20] Suwailam, M. M. B., O. F. Siddiqui, and O. M. Ramahi, "Mutual coupling reduction between microstrip patch antennas using slotted-complementary split-ring resonators," *IEEE Antennas Wireless Propagation Letters*, Vol. 9, 876-878, 2010.
[21] Shafique, M. F., Z. Qamar, L. Riaz, R. Saleem, and S. A. Khan, "Coupling suppression in densely packed microstrip arrays using metamaterial structure," *Microwave and Optical Technology Letters*, Vol. 57, No. 3, 759-763, 2015.
[22] Yang, X. M., X. G. Liu, X. Y. Zhu, and T. J. Cui, "Reduction of mutual coupling between closely packed patch antenna using waveguide metamaterials," *IEEE Antennas and Wireless Propagation Letters*, Vol. 11, 389-391, 2012.
[23] Qamar, Z. and H. C. Park, "Compact waveguided metamaterials for suppression of mutual coupling in microstrip array," *Progress In Electromagnetic Research*, Vol. 149, 183-192, 2014.
[24] Jeet Ghosh, Sandip Ghosal, Debasis Mitra, and Sekhar Ranjan Bhadra Chaudhuri, "Mutual Coupling Reduction between Closely Placed Microstrip Patch Antenna Using Meander Line Resonator", *Progress In Electromagnetic Research Letters, Vol. 59, 115-122, 2016.*
[25] Xu Yang, Ying Liu, Yun-Xue Xu, and Shu-xi Gong, "Isolation Enhancement in Patch Antenna Array With Fractal UC-EBG Structure and Cross Slot", *IEEE Antennas Wireless Propagation Letters*, VOL. 16, 2017, pp. 2175-2178.